DØ RUN II CALORIMETER ELECTRONICS

February 2, 2004

1 Calorimeter

2 Calorimeter Electronics

2.1 Overview

There are 55,296 calorimeter channels to be readout; 47,032 correspond to channels connected to physical readout modules in the cryostats. The readout is accomplished in three principal stages. In the first stage, the signals from the uranium-liquid argon detector are transported to charge preamplifiers located on the cryostats via low impedance coaxial cable. In the second stage, the signals from the preamplifiers are transported on twisted-pair cable to the signal shaping and analog storage circuits (baseline subtractors or BLS) located underneath the cryostats. The BLS use switched capacitor arrays (SCA) as analog storage devices to hold the signal for about 4 μs until the trigger is available, and provide baseline subtraction to remove any low frequency noise or pileup present in the signal. In addition, faster shaped analog sums of the signals are picked off to provide prompt inputs to the calorimeter trigger system for both the level 1 and level 2 trigger decisions. The precision signals from the BLS are bussed on an analog bus and driven by analog drivers over 130 m of twisted-pair cable to analog to digital converters (ADC) in a moveable counting house, and then enter the data acquisition system for the level 3 trigger decision and final storage of data to tape.

Figure 1 sketches a brief outline of the main components in the calorimeter readout chain.

2.2 Front-End Electronics

The signals from the uranium liquid argon calorimeter are transported on 30 Ω coaxial cable to a feedthrough port (the interface between the cold region and the warm region) on the cryostat and then on to the preamplifiers. The cables from feedthrough port to preamplifier were replaced to provide better impedence matching to the preamplifier input ($\sim$ 30 Ω) and to equalize the lengths to provide better timing characteristics by minimizing the spread of the signal arrival. Electron drift time in the 2.3 mm gap remains $\sim$450 ns at 2.0 kV for

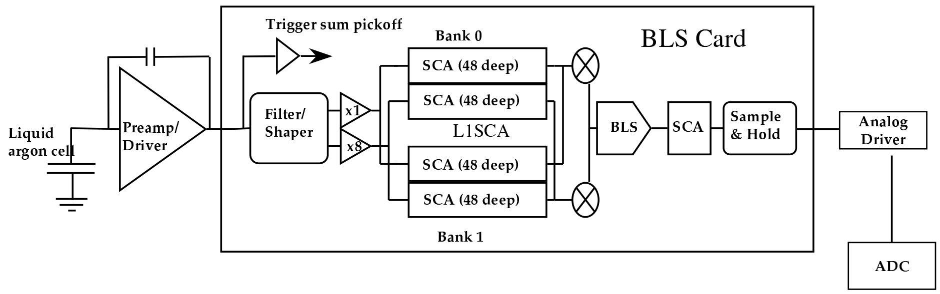

Figure 1: *Read-out chain of the calorimeter in Run II indicating the three major components: preamplifiers, base-line subtractor and storage circuitry (BLS) and the analog to digital convertors (ADC).*

Run II, which provides a challenge for signal charge integration with beam crossings occurring at 396 ns. The calorimeter electronics was designed to maintain the good signal to noise ratio from Run I in the expected high instantaneous rate environment in the original Run II design, with a minimum bunch crossing timing of 132 ns.

The preamplifiers are individually packaged transimpedence (i.e. charge to voltage) hybrid amplifiers on ceramic. Forty-eight individual preamplifier hybrids are mounted on a motherboard, with 96 motherboards housed in a single preamplifier box. Twelve such boxes, mounted on top of the calorimeter cryostats, make up the full system for the calorimeter readout. Since access to these preamplifier boxes is very limited, the power supplies for the preamplifiers are redundant with each preamplifier box having two supplies, any one of which can be switched in to replace a failed supply. Low noise commercial switching power supplies are used to provide the necessary power density.

A feedback RC circuit in the preamplifier's first stage performs a partial differentiation on the fully integrated output which compensates for the partial integration performed on the signal by the detector RC circuit, introduced by the detector capacitance and cable impedance. The goal is to make the preamplifier output waveform as similar as possible for all channels, by customizing the preamplifier RC feedback compensation to the detector capacitances of the various cells. Given the large range of detector capacitances at the input to the preamplifiers, there are 14 species of preamplifier (plus one for readout of the ICD) which provide similar output signal shapes into the BLS. This is important to maintain good timing for the peak-sampling circuit. The characteristics of the preamplifier species is shown in Table 1. The ICD feedback capacitor is 22 pF to lower the gain of the output signals to preserve their dynamic range.

Dual parallel input jFETs helps maintain low noise performance. Two output driver stages provide the capability to drive a terminated 115 Ω twisted pair cable. The power requirement of a single preamplifier is 280 mW. The noise performance can be evaluated from the width of the pedestal distribution,

Table 1: *Characteristics of the different preamplifier species used for the liquid argon calorimeter and the ICD readout.*

Preamplifier species	A	B	C	D	E	F	G	Ha-Hg	I
Avg. det. cap. (nF)	0.26 – 0.56	1.1 – 1.5	1.8 – 2.6	3.4 – 4.6	0.36 – 0.44	0.72 – 1.04	1.3 – 1.7	2 – 4	–
Layer readout	EM1,2, HAD	HAD	HAD	HAD	CC EM3	EC EM3,4	CC EM4, EC EM3,4	EC EM3,4	ICD
Feedback cap (pF)	5	5	5	5	10	10	10	10	22
RC (ns)	0	26	53	109	0	14	32	47 – 110	0
Total preamps	13376	2240	11008	8912	9920	7712	3232	896	384

which is a function of the detector input capacitance.

The preamplifier motherboard is an 8-layer printed circuit board, with ground or power planes of solid copper separating planes containing signal traces in order to minimize noise pickup and cross-talk. The motherboard houses the precision resistors (0.1% 10 kΩ and 20 kΩ value, depending on the preamplifier feedback capacitor) for the calibration voltage pulse. A single input line pulses six preamplifiers at once using a low capacitance trace. A discussion of the calibration system is presented below.

All this electronics is located in an area where there can be a residual few hundred gauss field, and hence the switching supplies have been magnetically shielded, and all other devices (including cooling fans) have been verified to function in the residual fields. New heat exchange systems were installed in the existing preamplifier boxes to deal with the increased power dissapation.

2.3 Signal Shaping and Trigger

The single-ended preamplifier signals are routed from the calorimeter over approximately 25 m of twisted pair cable to a region below the cryostats where there is significantly easier access. The baseline subtractor (BLS) boards are located in this region. These boards perform two functions: the first is signal shaping, analog storage and baseline subtraction used for digitization; the second is a fast analog trigger sum signal for the level 1 and level 2 calorimeter trigger.

In order to minimize the effects of pile-up, only 2/3 of the charge in the detector and collected by the preamplifier circuit is used in the shaper circuit. The preamplifier output is an integral of the detector signal characterized by a rise time of about 450 ns and a recovery time of 15 μs. Shaped signals are sampled every 132 ns, corresponding to 7 RF buckets from the Tevatron. The shaper circuit produces an unipolar signal with a peak at about 320 ns and a return to zero after ~ 1.2 μs. The shaped signal is sampled at 320 ns, close to the peak. To subtract the base-line, the signal three samples earlier (396 ns) is subtracted by the BLS circuitry.

The calorimeter level 1 and level 2 triggers are based on the energy measured in trigger towers of size 0.2×0.2 in $\Delta\eta \times \Delta\phi$, which is obtained by making appropriate sums (via resistor packs on the BLS boards) of the fast pickoffs at the shaper inputs. The resistor packs have been tuned based on a sampling weight optimization study which sought to minimize electron resolution first, and jet resolution second, given the channels included in the trigger (all but the coarse hadronic channels are included).

2.4 Digitization

The BLS board contains 48 channels consisting of 4 towers with up to 12 preamplifier signals ganged to form a pseudo-projective tower. There are signal shapers for each channel on the BLS motherboard and trigger pick-off and summation circuits tap the preamplifier signal prior to the shaper circuitry. The shaped preamplifier signals are fed to daughterboards, one per tower, each of which holds five SCA chips. The SCAs contain an array of 48 capacitors to pipeline the calorimeter signals, however the first and last buffer are not used in readout to avoid edge effects in the chips. The SCA is not designed for simultaneous read/write operations therefore two SCA banks are alternately employed for writing and reading the integrated charge prior to the level 1 trigger decision. This scheme provides the 4.2 μs buffering necessary prior to the arrival of the level 1 trigger decision. There are also two gain paths ($\times 1$ and $\times 8$) to match the ADC readout precision so four of the SCAs are used to store the signals for the twelve channels on a daughtercard until the level 1 trigger decision has been made. Once a positive level 1 decision is received, baseline subtractor circuitry on each daughterboard decides channel-by-channel which gain path to use and subtracts the stored baseline (from the sample 396 ns earlier) from the peak signal and stores the result in the level 2 SCA, which buffers the data until after a level 2 trigger decision. Once a level 2 trigger accept is issued, the data is transfered from the level 2 SCA to a sample-and-hold circuit on the daughterboard and an analog switch on the BLS motherboard buses the data on the BLS backplane to analog drivers which transfer the signal up to the ADC. The gain information is sent simultaneously on separate digital control cables.

The ADC successive approximation digitizers, reused from Run I, have only a 12-bit dynamic range, but the low and high gain path for each readout channel maintain the 15-bit dynamic range. This matches the measured accuracy of the SCA. The readout system is approximately deadtimeless up to a level 1 trigger accept rate of 10 kHz, assuming only one crossing per superbunch is read out.

A master control board synchronizes twelve independent controllers (one for each readout quadrant) in a shared VME crate that provide the timing and control signals that handle the SCA requirements and to interface to the level

1 and level 2 trigger systems. Each control board houses three Altera FPGA chips (10K series, 208-pin packages). Three FIFO pipelines buffer up to about 40 events awaiting readout at each trigger level. Timers on these event buffers ensure that "stale" data is appropriately flagged to the data acquisition system. Other readout errors are also flagged in the readout. The control boards also permit the readout to be run in numerous diagnositic or calibration modes.

2.5 Calibration System

The calorimeter calibration system consists of twelve identical units used for the liquid argon calorimeter and one slightly modified unit for the ICD. Each unit is composed of one pulser board and its power supply, located in the BLS racks on the detector platform, and six active fanout boards, housed inside the preamplifier boxes on the cryostats, and provides the calibration signal for one calorimeter quadrant. The pulser boards are controlled via a serial bus to a VME IO register, in order to set the amplitude and the delay of the calibration signal and to enable the channels to be pulsed.

The pulser board delivers both a DC current corresponding to the chosen pulse height for each selected channel and a differential ECL command signal to the fanout boards. The pulse heights are set via an 18-bit DAC, with a maximum current of 100 mA delivered, and the delays through six programmable 8-bit delay lines with a $\sim$ 2 ns step size. The delays allows more careful adjustment of the relative timing of the calibrated charge injection and the readout of the preamplifiers. Sixteen switches located on each fanout board each generate a precise pulse on the reception of a command signal, converting the DC current to a calibration pulse, which is then distributed through the preamplifier box backplane to 48 calorimeter channels.

Both the pulser board and the active fanout have been tested and shown to provide a pulser signal with a linearity at the per mil level and all the currents delivered are uniform within 0.2% between all boards and 0.1% within one board (see Figure 2a). All the pulse shapes have been measured to estimate systematic effects on the signal amplitude, the timing and the charge injected (see Figure 2b).

2.6 Gain Determination

For all calorimeter channels, the gain calibration factors are determined from the deviations of the slope ADC/DAC from its ideal value of 0.25. The factors obtained show a dependence with respect to the preamplifier type and the capacitance of a given cell. The dispersion of the coefficients for electromagnetic (hadronic) channels is about 5% (10%). Systematic shifts of the slope values can be observed for different preamplifier types.

Part of these differences are due to the injection of the calibration signal at the preamplifier input, outside of the cryostat. A fraction of the pulser signal travels down the signal cable and is reflected from the calorimeter cell, depending on the capacitance of the cell, and therefore has a different measured shape.

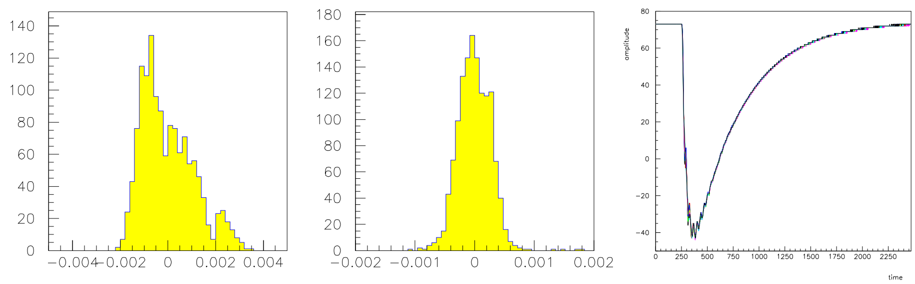

Figure 2: The mean current/DAC delivered by the pulser boards is 825 mA/DAC with a spread of ±0.2% for all 15 pulser boards produced (a) and 0.1% within one board (b). (c) Pulse shape measured at preamplifier input, amplitude(mV) vs time(ns).

The effects are largest for hadronic cells with a high capacitance, where differences in the timing can produce large tails in the distribution of the calibration coefficients. Figures 3a and 3b show the difference for a preamplifier of low capacitance (type A) for the electromagnetic readout and high capacitance (type D) for hadronic readout. Corrections for these effects have been derived for the calibration coefficients and the delay setting of the pulsers have been tuned to maximize the response in the electromagnetic layers.

Models of the electronics chain have been setup to evaluate the differences between the electronics response to a calibration signal and a detector signal. To render these models realistic all stable parameters of the signal path from the detector to the preamplifier input have been determined from reflection measurements. The reflected response (in arbitrary voltage units) to a step function is shown in Figure 3c for three different channel types. Quantitatively the values for the cable resistivity outside and inside the cryostat, the inductance of the feedthrough and the signal-strips as well as the capacitance of each cell have been determined and used in a simulation model. Recently estimated corrections to the calibration coefficients evaluate these effects at below the percent level for electromagnetic channels, when pulsed close to the signal maximum.

2.7 Liquid Argon Monitoring

The purity of the liquid argon is critical to the detector performance as electronegative contaminants (e.g. oxygen and nitrogen) can combine with electrons traversing the gap and can severely impact the energy measurement. The liquid argon was recovered from Run I and, before refilling the cryostats for Run II, the purity was remeasured with an external argon test cell equipped with an alpha source (^{241}Am which was also used for purity measurements in Run I) and a beta source (^{106}Ru – this was a new source with activity of 30-40 kBq, produced by Isotope Products). Calibration of the test cell was performed by injecting controlled amounts of O_2 into pure argon (cylinders of Ar Ultra Plus Grade UN1006 Linde at 0.1 ± 0.07 ppm). The pollution of the liquid argon was

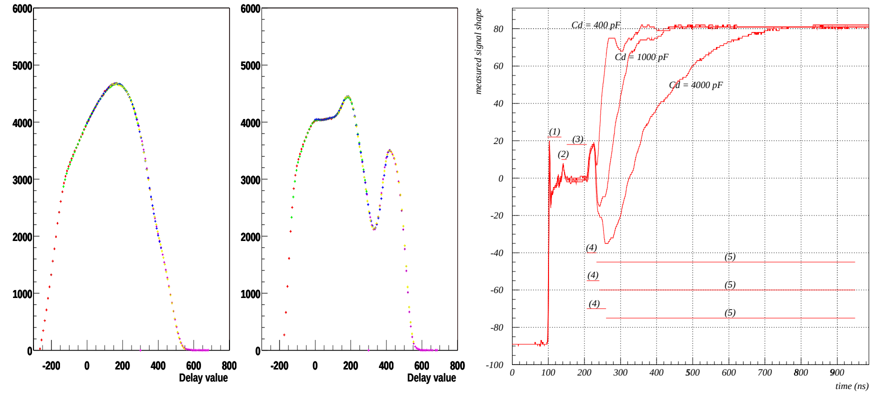

Figure 3: Signal shape (ADC vs. pulser delay unit/ns$\times$2) for an electromagnetic (a) and an hadronic (b) channel after readout obtained by incrementing the delay of the pulser signal: time = 0 for the signal is on the right axis. (c) Response to reflection measurement for three different channels. The vertical voltage scale is in arbitrary units.

measured to be less than 0.50 ± 0.15 ppm for all three calorimeter cryostats.

Radioactive sources are used to monitor the contamination levels *in situ*. Each of the three cryostats is equipped with four ^{241}Am sources (5 MeV α-particles, 432 yr half-life) with an activity of 0.1 μCi and four ^{106}Ru sources (maximum 3.5 MeV β-particles, $\sim$1 yr half-life). Three of the beta sources in each cryostat now have very low levels of activity ($\leq$ 1 Bq), ten years after the initial detector construction. One slightly stronger source has an activity of about 4 Bq. The charge liberated in the liquid argon gap for the alpha sources is about 4 fC (about 25,000 electrons) and about half this for the beta source. The expected trigger rate is about 500 Hz for the alpha source and 0.3 Hz for the strong beta source.

A new readout board with preamplifier, dual operational-amplifier and differential driver sends the amplified signals via shielded twisted-pair cable to a differential receiver board to be digitized by a 12-bit ADC using a Xilinx FPGA (Spartan XCS40XL). Histograms can be accumulated very rapidly (few kHz) on the receiver board which are read out via CAN-bus to a PC (running National Instruments LabView). This design is a modification of the liquid argon monitoring system for ATLAS and should be sensitive to less than 1 ppm of oxygen equivalent contamination. This design minimizes the possible introduction of noise into the calorimeter cryostats as no digital electronics is needed on the frontend crates. Ground loops are also prevented using the differential drivers.

The response of the signal is also a function of the liquid argon temperature so this will be monitored as well. The temperatures of the cryostats varied by less than 1% over the course of Run I.